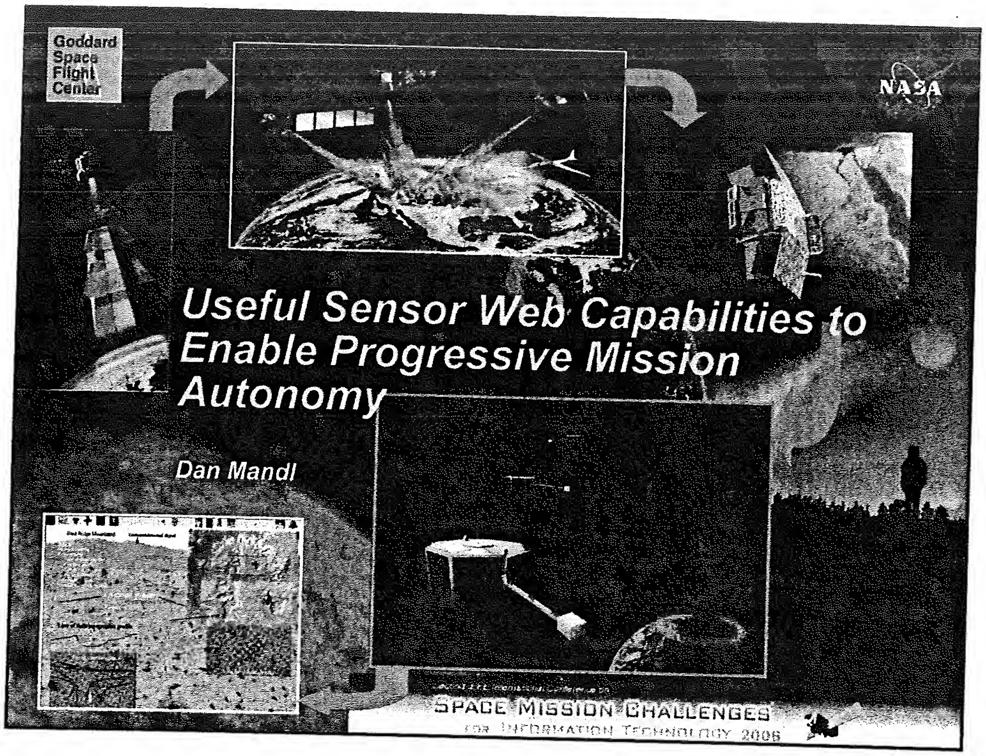


Agenda

- Statement of challenges
- Capabilities to meet challenges
- Experiments run with real satellites to validate new capabilities
  - EO-1
  - CHIPS
  - ST-5
- Conclusion

2

Challenges for Future Missions

- Manage increased mission complexity at lower cost
- Create flexible missions with interoperable components
- Increase mission safety by embedding intelligence to manage security and hazard avoidance

3

Key Capabilities To Meet Challenges

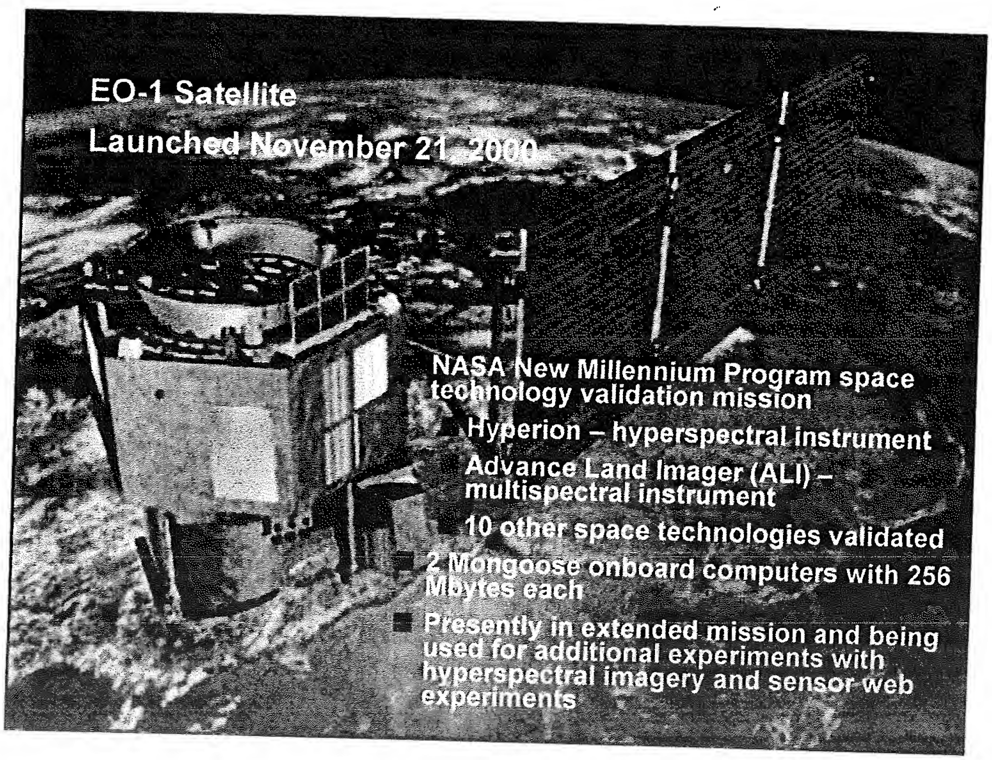
- Transition from centralized mission control to distributed control
- Maximize interoperability by abstracting as much mission functionality as possible
- Develop and use self-managing software components (autonomic computing)
  - (1) Components have self-awareness
  - (2) Self-optimization
  - (3) Self-healing
  - (4) Self-protection
  - (5) Negotiates (peer-to-peer) for resources
  - (6) Functions in a heterogeneous world and with open standards
  - (7) Anticipates needed resources and hides details needed to obtain resources

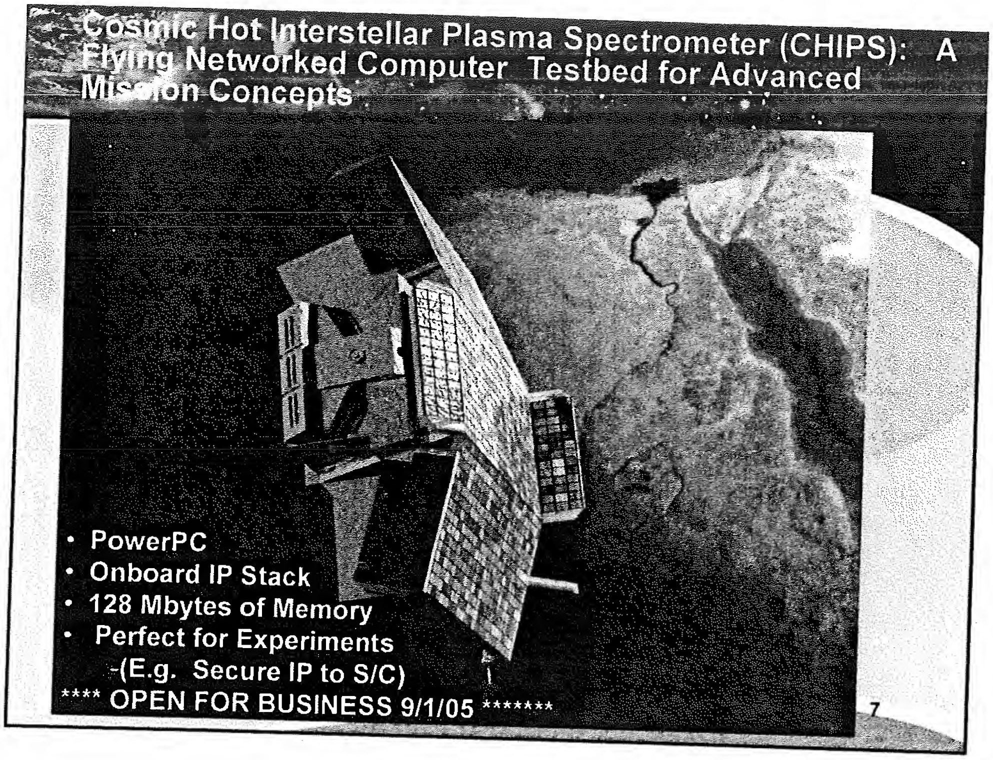
4

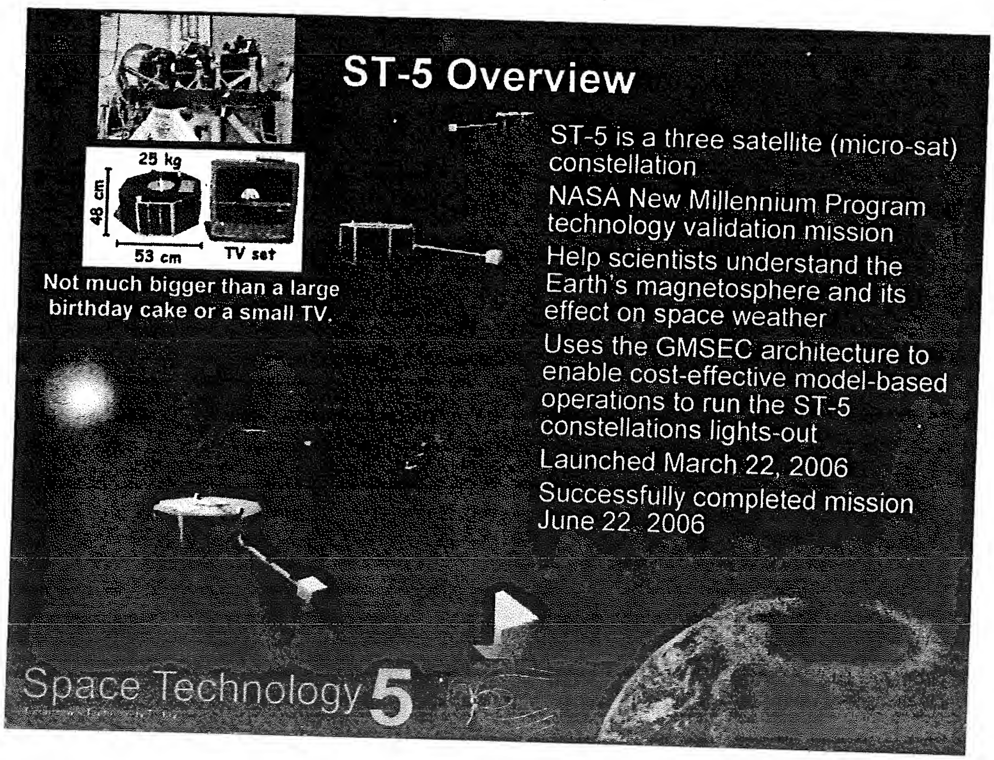
Series of Experiments Conducted

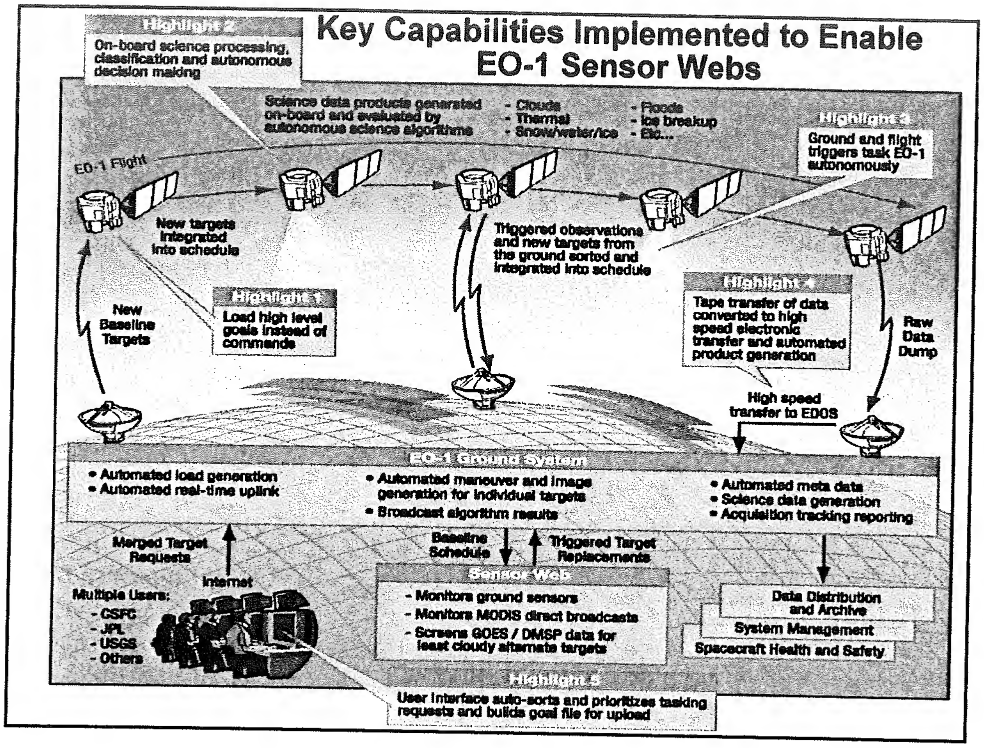
- Used following missions to conduct experiments to facilitate these capabilities:
  - Earth Observing 1 (EO-1)
  - Cosmic Hot Interstellar Plasma Spectrometer (CHIPS)
  - Space Technology 5 (ST-5)
- Experiment with Service Oriented Architectures (SOA)

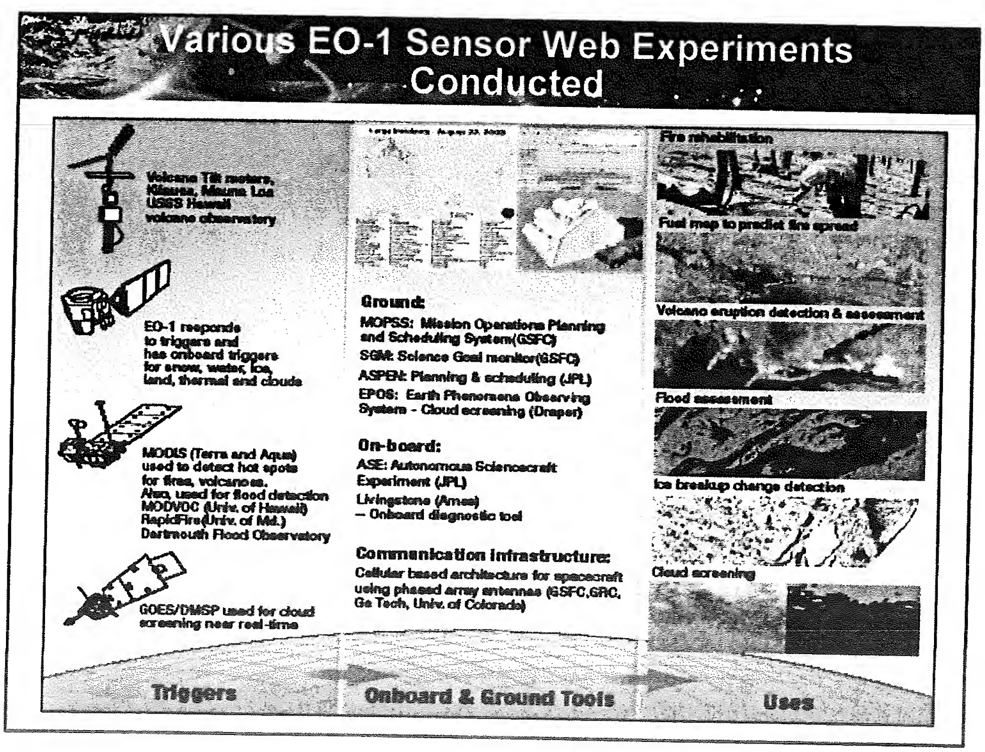
5

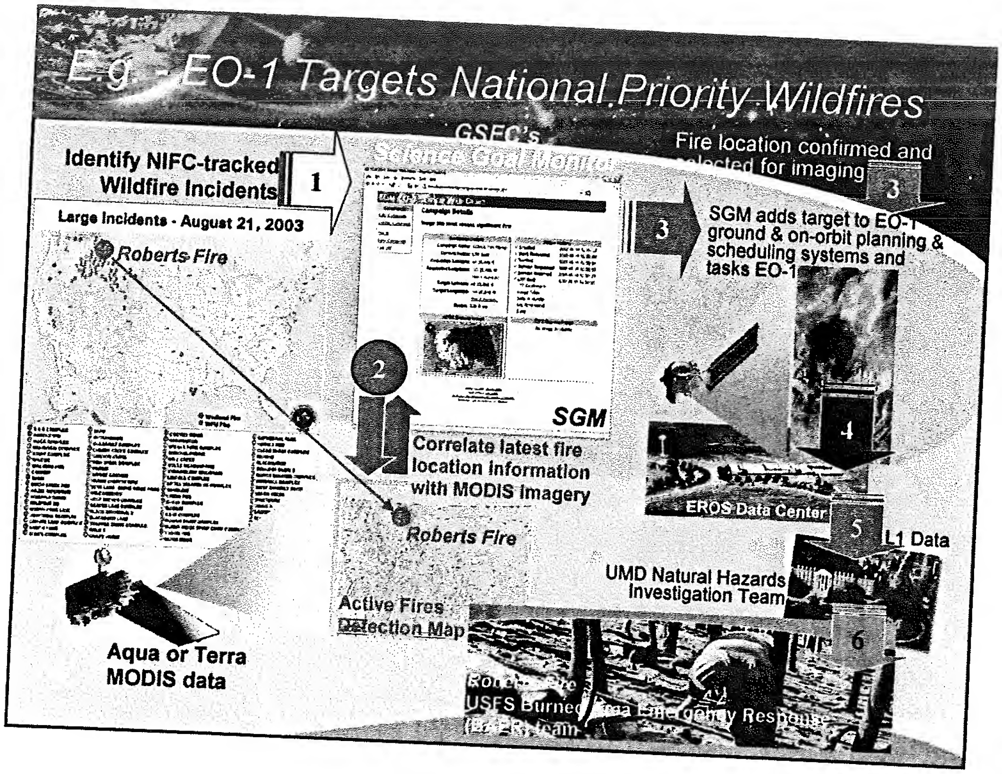


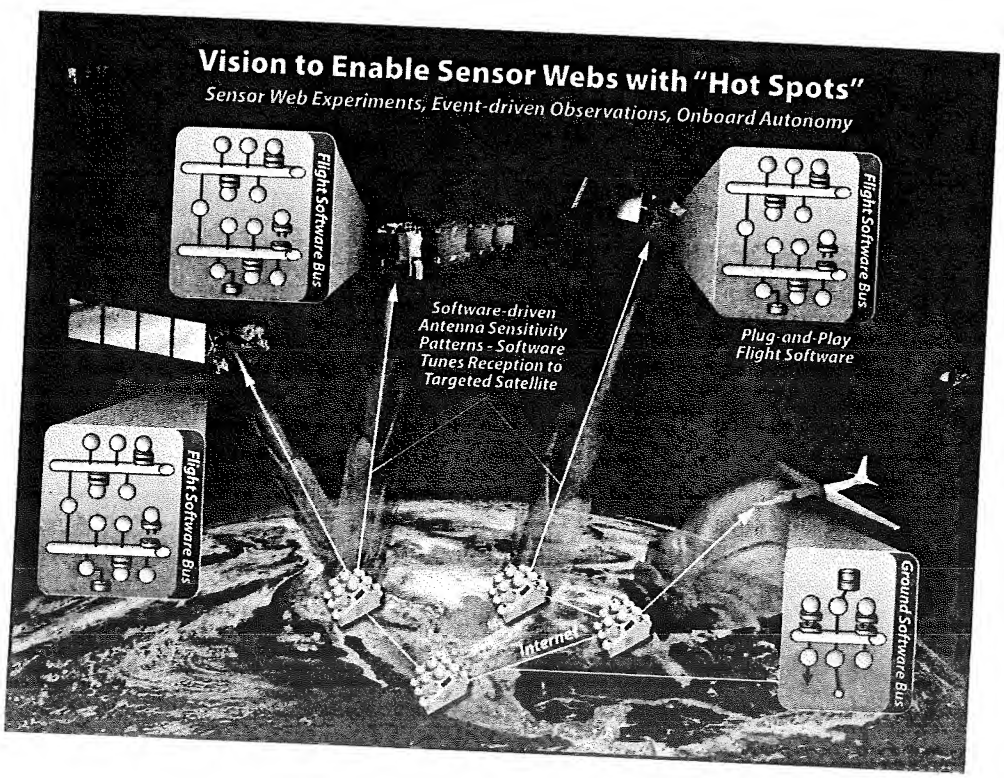

Cosmic Hot Interstellar Plasma Spectrometer (CHIPS): A Flying Networked Computer Testbed for Advanced Mission Concepts
• PowerPC
• Onboard IP Stack
• 128 Mbytes of Memory
• Perfect for Experiments
-(E.g. Secure IP to S/C)
**** OPEN FOR BUSINESS 9/1/05 *******
7


ST-5 Overview
25 kg
48 cm
53 cm
TV set
Not much bigger than a large birthday cake or a small TV.
ST-5 is a three satellite (micro-sat) constellation
NASA New Millennium Program technology validation mission
Help scientists understand the Earth's magnetosphere and its effect on space weather
Uses the GMSEC architecture to enable cost-effective model-based operations to run the ST-5 constellations lights-out
Launched March 22, 2006
Successfully completed mission June 22, 2006
Space Technology 5


Key Capabilities Implemented to Enable EO-1 Sensor Webs
Highlight 2
On-board science processing, classification and autonomous decision making
Science data products generated on-board and evaluated by autonomous science algorithms
- Clouds
- Thermal
- Snow/water/ice
- Floods
- Ice breakup
- Etc...
Highlight 3
Ground and flight triggers task EO-1 autonomously
EO-1 Flight
New targets integrated into schedule
Triggered observations and new targets from the ground sorted and integrated into schedule
Highlight 1
Load high level goals instead of commands
New Baseline Targets
Highlight 4
Tape transfer of data converted to high speed electronic transfer and automated product generation
Raw Data Dump
High speed transfer to EDOS
EO-1 Ground System
• Automated load generation
• Automated real-time uplink
• Automated maneuver and image generation for individual targets
• Broadcast algorithm results
• Automated meta data
• Science data generation
• Acquisition tracking reporting
Merged Target Requests
Internet
Baseline Schedule
Triggered Target Replacements
Sensor Web
- Monitors ground sensors
- Monitors MODIS direct broadcasts
- Screens GOES / DMSP data for least cloudy alternate targets
Multiple Users:
- GSFC
- JPL
- USGS
- Others
Data Distribution and Archive
System Management
Spacecraft Health and Safety
Highlight 5
User Interface auto-sorts and prioritizes tasking requests and builds goal file for upload


Various EO-1 Sensor Web Experiments Conducted
Volcano Tilt meters, Kilauea, Mauna Loa USGS Hawaii volcano observatory
EO-1 responds to triggers and has onboard triggers for snow, water, ice, land, thermal and clouds
MODIS (Terra and Aqua) used to detect hot spots for fires, volcanoes. Also, used for flood detection MODVOC (Univ. of Hawaii) RapidFire (Univ. of Md.) Dartmouth Flood Observatory
GOES/DMSP used for cloud screening near real-time
Ground:
MOPSS: Mission Operations Planning and Scheduling System(GSFC)
SGM: Science Goal monitor(GSFC)
ASPEN: Planning & scheduling (JPL)
EPOS: Earth Phenomena Observing System - Cloud screening (Draper)
On-board:
ASE: Autonomous Sciencecraft Experiment (JPL)
Livingstone (Ames)
– Onboard diagnostic tool
Communication Infrastructure:
Cellular based architecture for spacecraft using phased array antennas (GSFC,GRC, Ga Tech, Univ. of Colorado)
Fire rehabilitation
Fuel map to predict fire spread
Volcano eruption detection & assessment
Flood assessment
Ice breakup change detection
Cloud screening
Triggers
Onboard & Ground Tools
Uses


E.g. - EO-1 Targets National Priority Wildfires
Identify NIFC-tracked Wildfire Incidents
1
Large Incidents - August 21, 2003
Roberts Fire
GSFC's
Fire location confirmed and
selected for imaging
3
SGM adds target to EO-1 ground & on-orbit planning & scheduling systems and tasks EO-1
3
2
SGM
Correlate latest fire location information with MODIS imagery
4
EROS Data Center
5
L1 Data
Roberts Fire
UMD Natural Hazards Investigation Team
Active Fires Detection Map
6
Aqua or Terra MODIS data
USFS Burned
Response

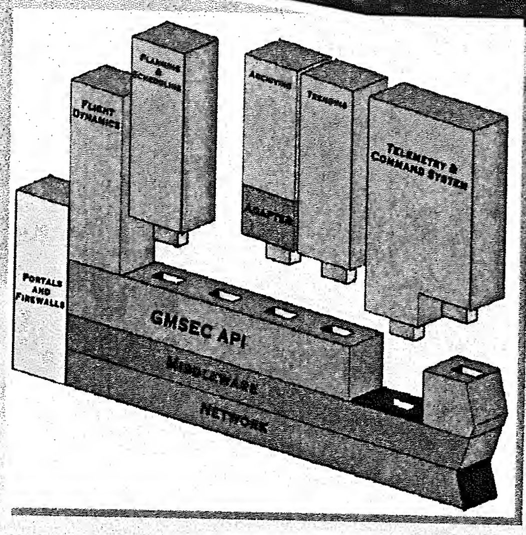

Vision to Enable Sensor Webs with "Hot Spots"
Sensor Web Experiments, Event-driven Observations, Onboard Autonomy
Flight Software Bus
Flight Software Bus
Software-driven Antenna Sensitivity Patterns - Software Tunes Reception to Targeted Satellite
Plug-and-Play Flight Software
Flight Software Bus
Internet
Ground Software Bus

Underlying "Plug and Play" Message Bus Architecture-- Goddard Mission Services Evolution Center (GMSEC)

GMSEC architecture provides a scalable and extensible ground and flight system approach

- Standardized messages formats
- Plug-and-play components
- Publish/Subscribe protocol
- Platform transparency

More info at: http://gmsec.gsfc.nasa.gov



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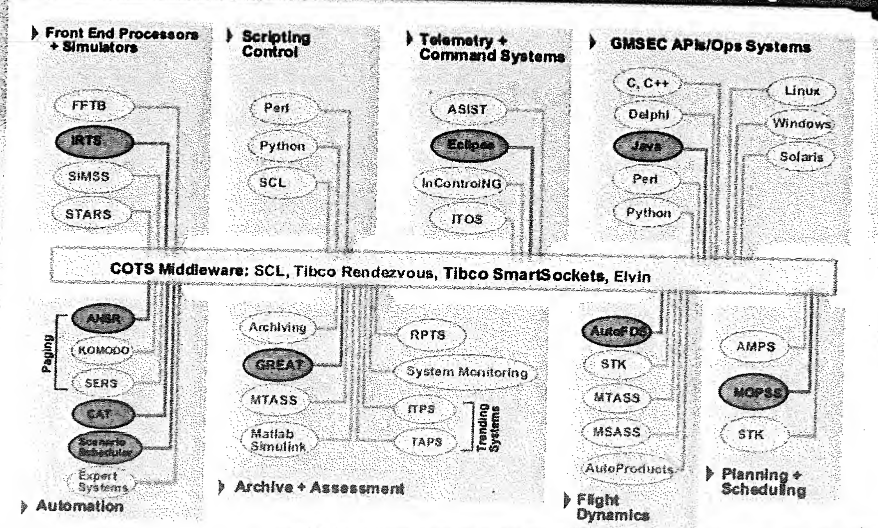
GMSEC Component Catalog

GMSEC approach gives users choices for the components in their system. The TRMM mission has selected key components from the GMSEC catalog.



ST-5 Lights-Out Autonomy

- ST-5 mission demonstrated parts of (1), (2), (5), (6) and (7) (from slide 3)
  - Lights-out operations with model-based software
    - Predict problems before they happen and fix early
    - Models update themselves automatically
    - Modeling system is built on top of "plug and play" architecture to enable easy extensibility
  - Act as stepping stone for this type of capability for future missions

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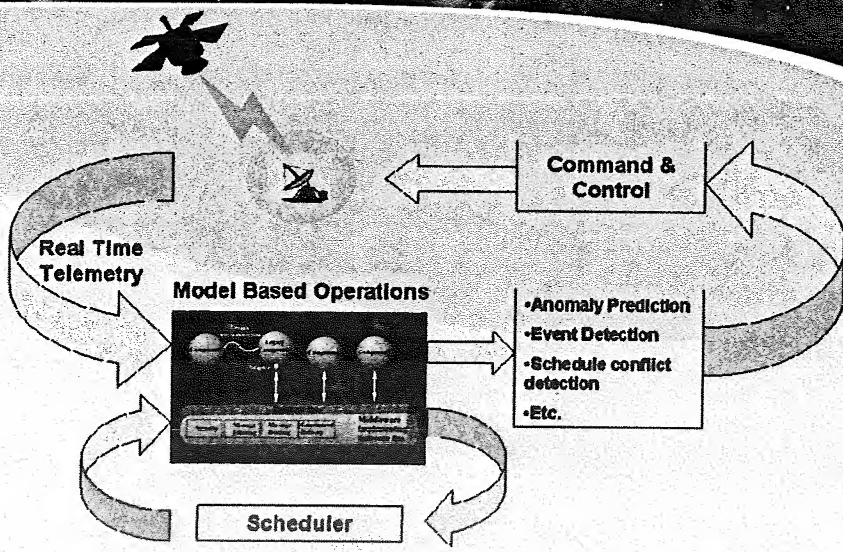
ST-5 Model-Based Operations Overview



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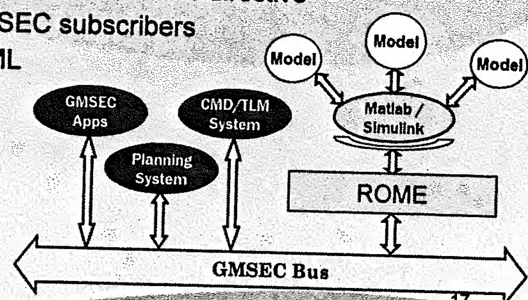
ST-5 ROME Framework

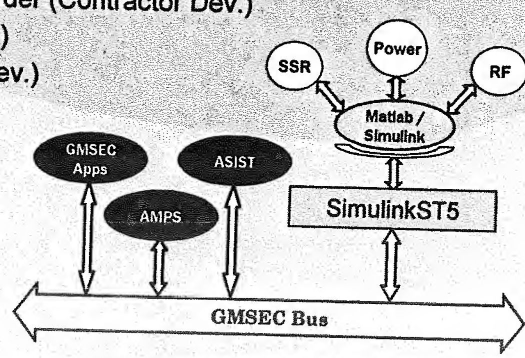
- Real-time Object Modeling Executive (ROME)
  - Supports multiple models and multiple spacecraft
  - Leverages common engineering modeling environments
  - Models from various sources are easily integrated
  - Fully supports GMSEC bus
  - Models initialized and maintained from telemetry
  - Model control via configuration file or bus directive
  - Results available to GMSEC subscribers
  - Easily configured via XML
  - Highly scalable



17

ST5 Specific Configuration

- ROME based implementation
- Dynamic characterization of sub-systems phenomenology
- Used by mission to manage constrained resources
- Models of Subsystems
  - Solid State Recorder (Contractor Dev.)
  - RF (Student Dev.)
  - Power (Project Dev.)



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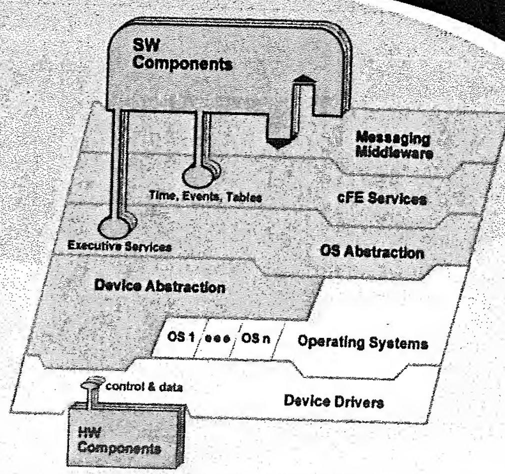
SimulinkST5 GMSEC Highlights

- Simulink is a visual interface to MatLab to allow users to simulate systems that can be represented with mathematical equations
- Features of Simulink as used on ST5 are as follows:
  - Standardized messaging interoperability
  - GMSEC Compliance
    - Directives
      - Advanced Mission Planning System (AMPS)
      - Advanced Spacecraft Integration and System Test (ASIST) system
    - Mnemonic Value Messages
      - ASIST
      - Integrated Test and Operations System (ITOS) capability
    - Heartbeat messages
    - Log messages
    - Product Messages
  - Predictive Model-Based Operations
    - Subsystem models to anticipate platform conditions in a constellation environment.
      - Support Short and Long Term Mission Planning
    - Interact with AMPS and ASIST for control directives, telemetry, and profile events.
  - Constellation Operations Support

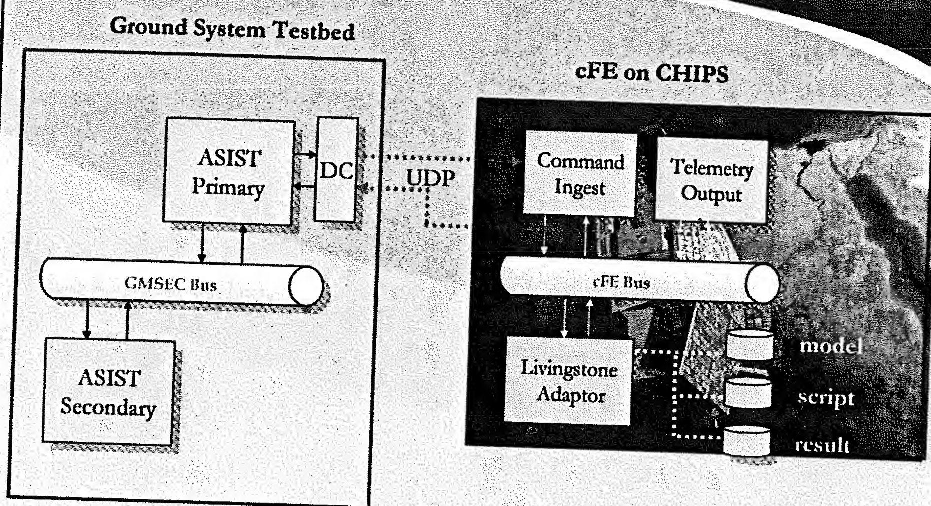
Core Flight System (CFS) and Extension for GMSEC for Flight SW

CFS provides a framework that simplifies the development and integration of applications

- Layered Architecture – software of a layer can be changed without affecting the software of other layers
- Components communicate over a standard message-oriented software bus, therefore, eliminating the need to know the details of the lower layers of inter-networking.
- Software components can be developed and reused from mission to mission.
- Developed by Flight SW Branch at GSFC
- More info at: http://gmsec.gsfc.nasa.gov



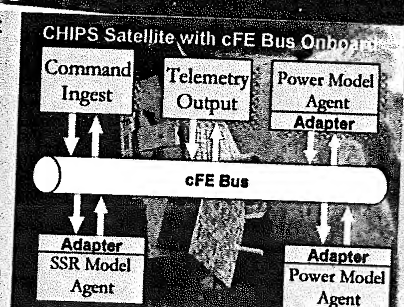
Onboard Integrated Message Bus Demonstration (December 2005)

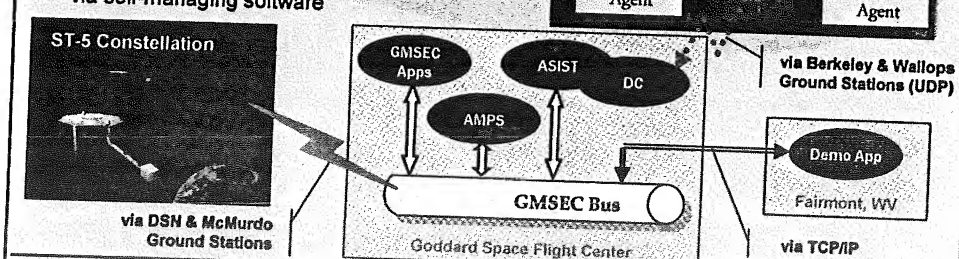


DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test

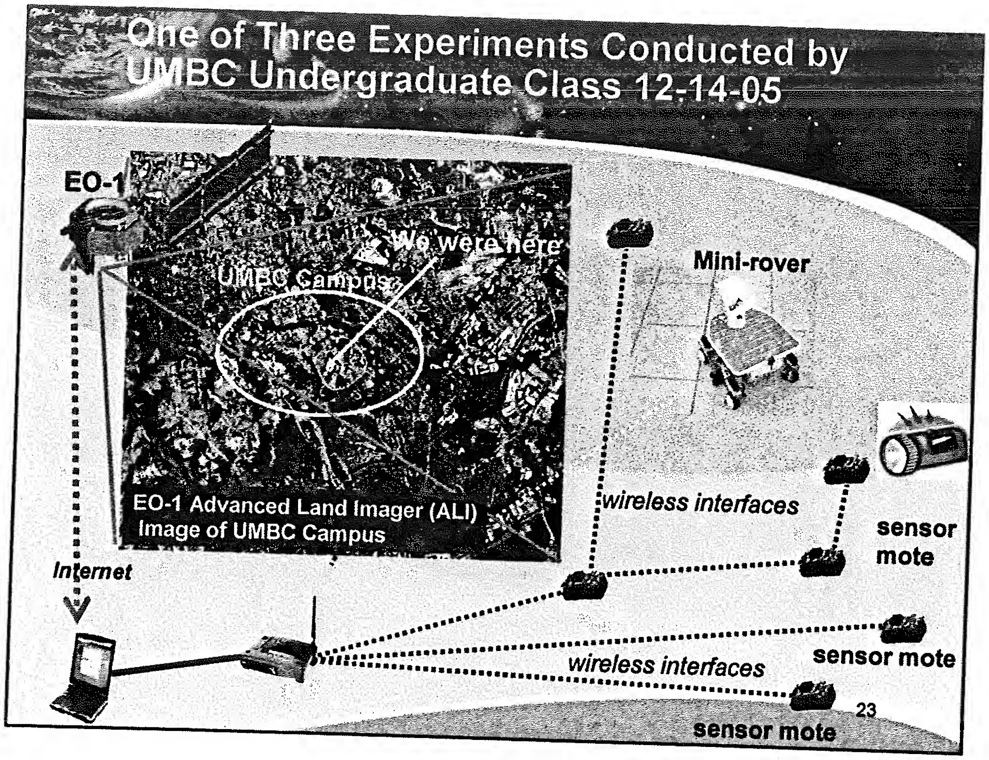
Moving Models Onboard CHIPS Satellite Under cFS to Demonstrate Mobile Agents

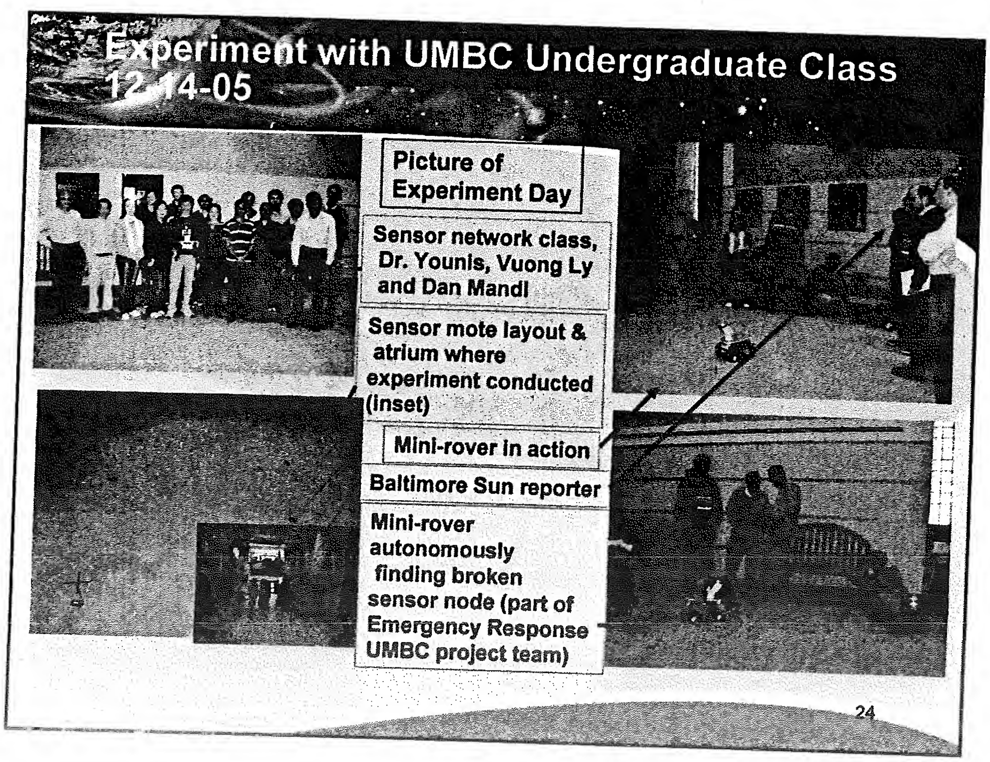
- Mobile agent –autonomous software module that can easily be moved around a network
- Models transformed into mobile agents
  - Worked with Solid State Recorder agent (model) first
- Adapter built to make compatible with both GMSEC and Core Flight Executive (cFE)
- Demonstrated capability to move software running on GMSEC onboard to run under cFE
- Demonstrates beginning step to transform missions from central control to distributed control via self-managing software



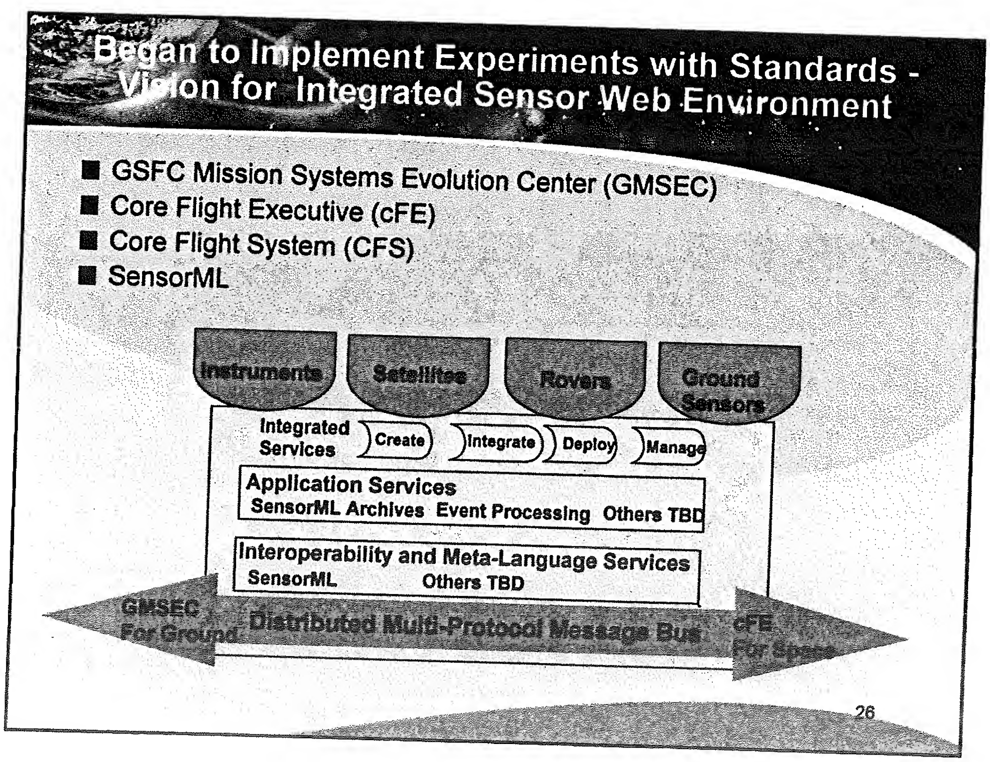


CHIPS – Cosmic Hot Interstellar Plasma Spectrometer
ST-5 – Space Technology 5
DC – Data Center
ASIST – Advanced Spacecraft Integration and System Test


One of Three Experiments Conducted by UMBC Undergraduate Class 12-14-05
EO-1
We were here
UMBC Campus
Mini-rover
EO-1 Advanced Land Imager (ALI) Image of UMBC Campus
wireless interfaces
sensor mote
Internet
sensor mote
wireless interfaces
sensor mote
23


Experiment with UMBC Undergraduate Class 12-14-05
Picture of Experiment Day
Sensor network class, Dr. Younis, Vuong Ly and Dan Mandl
Sensor mote layout & atrium where experiment conducted (inset)
Mini-rover in action
Baltimore Sun reporter
Mini-rover autonomously finding broken sensor node (part of Emergency Response UMBC project team)
24


Closer Look at our Mini-Rovers &
Simulated Mars Landscape at GSFC


Began to Implement Experiments with Standards -
Vision for Integrated Sensor Web Environment
■ GSFC Mission Systems Evolution Center (GMSEC)
■ Core Flight Executive (cFE)
■ Core Flight System (CFS)
■ SensorML
Instruments
Satellites
Rovers
Ground Sensors
Integrated Services
Create
Integrate
Deploy
Manage
Application Services
SensorML Archives
Event Processing
Others TBD
Interoperability and Meta-Language Services
SensorML
Others TBD
GMSEC For Ground
Distributed Multi-Protocol Message Bus
cFE For Space
26

Sensor Modeling Language (SensorML)

- Standard models and Extensible Markup Language (XML) schema
  - Describes sensor systems to provide information needed to discover and locate sensor and sensor observations
  - Process low-level observations
  - Defines interfaces
  - Lists taskable properties
- Can apply to any sensor whether in-situ or remote
- Facilitates "plug and play" and interoperability between sensors
  - Especially useful for heterogeneous sets of sensors and rapid integration of new sensors

More info at--- http://vast.nsstc.uah.edu/SensorML/

Good article at-- http://www.geoplace.com/gw/2004/0406ogc.asp

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OGC EO-1 Experiment

- A proposal was submitted and accepted by the Open Geospatial Consortium (OGC) to use EO-1 as part of a testbed effort beginning June 2006 and lasting until December 2006.
  - Testbed effort called OGC Web Services (OWS) – phase 4 has may objectives, one of which is Sensor Web Enablement (SWE) for sensors via a standard which is similar to a Service Oriented Architecture (SOA)
  - More info at: http://www.opengeospatial.org/initiatives/?iid=199
  - Sponsored by many organizations including NASA, NGA, GeoConnections – Canada, National Technology Alliance, GSA, ORNL, LMCO, BAE, Ordinance Survey – UK, NATO C3, and TeleAtlas

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OGC EO-1 Experiment

- Figure on next slide depicts the portion of the demonstration in which EO-1 will participate; generic capability to discover and task EO-1 on the Internet via the following services:
  - Sensor Planning Service (SPS) – a standard Web service interface for requesting, filtering and retrieving sensor observations
  - Sensor Alert Service (SAS) – a standard interface for asynchronous notification of messages or alerts from sensors or sensor services
  - Sensor Registration Service (SRS) – a standard Web service to store sensor characteristics for later user retrieval
- Geospatial Interoperability Office at GSFC (M Bambacus, Nadine Alameh) major sponsor of OGC activities (and in particular OWS-4)and are monitoring this activity

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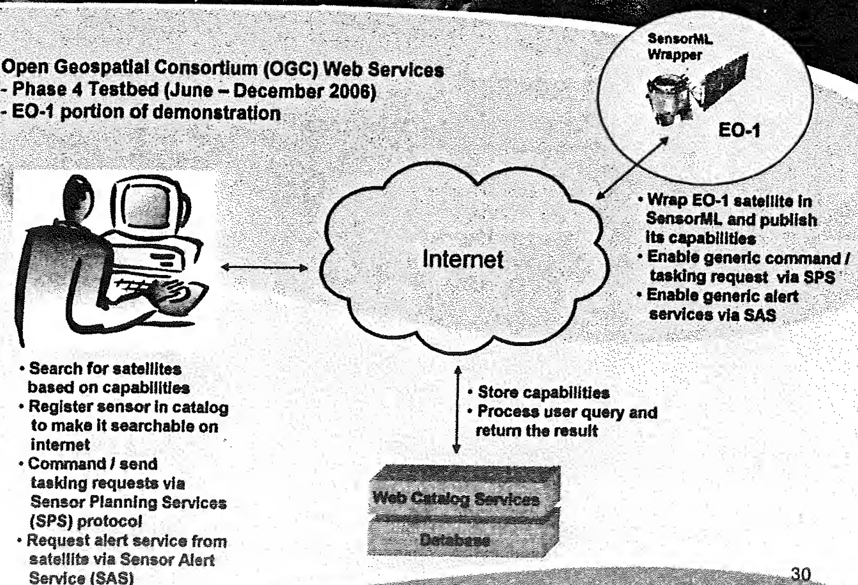
EO-1 Participation in OGC Web Services – Phase 4 Testbed; June 2006 – December 2006

Open Geospatial Consortium (OGC) Web Services
- Phase 4 Testbed (June – December 2006)
- EO-1 portion of demonstration



30

Conclusion

- Building capabilities to enable progressive mission autonomy via the use of three satellites and a series of increasingly more capable experiments
- Focusing on validating distributed mission control and maximizing interoperability
  - Enable changes to mission post launch
  - Combine existing missions into temporary "virtual constellations" to enable new missions

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Conclusion

- Will add additional real experiments to continue to build the toolbox
  - Two recent awards for AIST ESTO call for proposal will be used
    - *An Inter-operable Sensor Architecture to Facilitate Sensor Webs in Pursuit of GEOSS – Related to OGC effort*
      - *Key topic - Interoperability*
      - PI: Dan Mandl - 3 year effort
    - *Using Intelligent Agents to Form a Sensor Web for Autonomous Mission Operations*
      - Key topic distributed mission control
      - PI: Ken Witt/ISR Co-I Dan Mandl/GSFC – 3 year effort

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Conclusion

- Other related awards from AIST ESTO call in March 2006 will allow possible further synergy
  - E.g. - *Increasing the Technology Readiness of SensorML for Sensor Webs*
    - » Key topic SensorML for sensor interoperability
    - » PI- Michael Botts/Univ. of Alabama – 3 year effort

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